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# Growth of Western Larch After Thinning From Above and Below to Several Density Levels: 10-Year Results

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## Abstract

The 10-year growth of a 55-year-old, even-aged western larch (Larix occidentalis Nutt.) stand after it was thinned from above and below to a wide range of stocking levels was measured in eastern Oregon. Basal area and volume growth increased as stand density increased for both thinning methods. Despite heavy infestations of the larch casebearer during the last 4 years, diameter growth was greater in the second 5-year period than the first, but height growth was reduced considerably because of top dieback.

Thinning from above reduced net volume growth because of mortality caused by windthrow and exposure, although surviving trees responded well to increased growing space during the second period. Thinning from below is recommended in unmanaged larch stands.

Keywords: Growth response, thinnings (-stand volume, increment -)growing stock management, growing stock (-increment/yield, stand density, western larch, Larix occidentalis.



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## Introduction

Many even-aged western larch (*Larix occidentalis* Nutt.) stands in northeastern Oregon are heavily overstocked in the seedling and sapling stage and require thinning to concentrate growth on fewer trees that will be merchantable sooner. Levels-of-growing-stock and spacing studies in such stands provide data on long-term growth and yield that are useful in the development of managed yield tables and to verify simulation models designed to predict growth and yield for management alternatives.

This note presents results from a levels-of-growing-stock study begun in 1970 in the Blue Mountains of northeastern Oregon.[2] The study was designed to obtain basic information on the growth of even-aged larch stands thinned to several density levels by two methods. Results for the first 5 years of this study were reported by Seidel (1975).

## Study Area

The study is located on Boise-Cascade land about 6 miles northwest of Elgin, Oregon, on a gentle east-facing slope at an elevation of about 3,000 feet. The stand, 55 years old when first thinned in 1970, has a site index of about 83 feet at age 50.[3] The soil is classified as a Tolo silt loam, which is a well-drained Regosol developed from dacite pumicite originating from the eruption of Mount Mazama (Crater Lake) 6,500 years ago. It is underlain at a depth of about 4 feet by a buried soil developed from basalt.

The larch stand on the study area is a seral stage of an *Abies grandis/Pachistima myrsinites* plant community (Franklin and Dyrness 1973). Many genera of shrubs and herbs--*Thalictrum*, *Symphoricarpos*, *Smilacina*, *Trifolium*, *Spiraea*, *Vicia*, *Rosa*, *Fragaria*, *Osmorhiza*, and *Anemone*--are found. Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco), grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), and ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) are also present.

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[2] A cooperative research effort between the Boise-Cascade Corporation and the Pacific Northwest Forest and Range Experiment Station.

[3] Site index based on curves in "Ecology and Silviculture of Western Larch Forests" (Schmidt et al. 1976).

## Methods

The study consists of a 4 by 2 factorial randomized complete block design replicated two times for a total of sixteen 0.286-acre plots. It is designed for thinning at 10-year intervals, with remeasurement every 5 years. The first factor, density, consists of four levels: 50, 90, 130, and 170 square feet of basal area per acre. The second factor is the thinning method: from above (cutting the largest trees--dominants and codominants) and from below (cutting the smallest trees--suppressed, intermediate, and smaller codominants). Split-plot analyses of variance were used to test significance of treatment effects for two 5-year periods (1970-74 and 1975-79); regression analyses related diameter, basal area, and volume growth to residual basal area for each period.

All plots were well stocked before treatment, ranging from 191 to 226 square feet of basal area per acre (table 1). Trees were spaced from 8.5 to 10.3 feet apart; average d.b.h. ranged from 8.2 to 9.8 inches before thinning. All plots after thinning from above contained 2 to 8 percent of Douglas-fir, grand fir, or Engelmann spruce except one plot where 22 percent of the residual basal area was grand fir and Douglas-fir. All trees in plots thinned from below were larch.

Plots were thinned with a Drott "feller-buncher"[4] before growth began in 1970. This machine uses shears and a grapple mounted on a 25-foot boom with a crawler tractor undercarriage. Operation of this equipment required prior removal of all trees (clearcut) in swaths 20 feet wide. Swaths were spaced 50 feet apart and oriented east and west through the stand (fig. 1). The feller-buncher moved along these clearcut strips, reaching 25 feet into the thinning strips to cut and remove the entire tree. Some variation in residual stocking levels between replications and between thinning methods for a given density level existed because a few trees marked for cutting were missed and some leave trees were accidentally pushed over by the feller-buncher.

In April 1980, 10 years after the first thinning, plots were thinned for the second time with chain saws. Plots were not thinned to the original density levels after the 1970 thinning but were marked to allow an 8-percent increase in basal area, approximately the normal increase in stand density with age. The adjusted density levels after the second thinning were 54, 97, 140, and 184 square feet of basal area per acre.

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[4]Mention of companies or products is for the convenience of the reader. Such mention does not imply endorsement by the U.S. Department of Agriculture to the exclusion of other products or services that may be suitable.

Table 1--Stand characteristics per acre of western larch before and after the 1970 and 1980 thinnings and in 1975[1]/

| Density level[2]/ | Basal area | Number of trees | Average spacing | Average diameter | Average height[3]/ | Volume[4]/ Total | Volume[4]/ Merchantable, including ingrowth | |
|---|---|---|---|---|---|---|---|---|
| | Square feet | | Feet | Inches | Feet | Cubic feet | Cubic feet | Cubic feet |
| **Before initial (1970) thinning** | | | | | | | | |
| Thinned from above: | | | | | | | | |
| 1 | 221.5 | 420 | 10.2 | 9.8 | 85.1 | 7,177 | 6,635 | 26,816 |
| 2 | 191.5 | 495 | 9.4 | 8.4 | 80.3 | 6,032 | 5,331 | 18,540 |
| 3 | 213.7 | 408 | 10.3 | 9.8 | 90.1 | 6,883 | 6,164 | 27,020 |
| 4 | 202.0 | 513 | 9.2 | 8.5 | 82.0 | 6,285 | 5,311 | 18,045 |
| Thinned from below: | | | | | | | | |
| 1 | 211.0 | 490 | 9.4 | 8.9 | 95.3 | 6,892 | 6,202 | 24,555 |
| 2 | 205.5 | 557 | 8.8 | 8.2 | 91.8 | 6,688 | 5,942 | 20,898 |
| 3 | 221.5 | 596 | 8.5 | 8.3 | 93.7 | 7,192 | 6,366 | 19,479 |
| 4 | 226.0 | 525 | 9.1 | 8.9 | 92.4 | 7,402 | 6,689 | 26,446 |
| **After 1970 thinning[5]/** | | | | | | | | |
| Thinned from above: | | | | | | | | |
| 1 | 50.6 | 133 | 18.1 | 8.4 | 85.1 | 1,647 | 1,439 | 2,816 |
| 2 | 93.8 | 257 | 13.0 | 8.2 | 80.3 | 2,906 | 2,506 | 5,687 |
| 3 | 126.0 | 231 | 13.7 | 10.0 | 90.1 | 4,091 | 3,792 | 13,990 |
| 4 | 153.0 | 400 | 10.3 | 8.4 | 82.0 | 4,670 | 4,080 | 10,054 |
| Thinned from below: | | | | | | | | |
| 1 | 48.9 | 58 | 27.4 | 12.4 | 94.8 | 1,686 | 1,593 | 8,331 |
| 2 | 87.7 | 115 | 19.5 | 11.9 | 91.8 | 2,974 | 2,796 | 13,503 |
| 3 | 131.8 | 196 | 14.9 | 11.1 | 93.7 | 4,448 | 4,161 | 16,790 |
| 4 | 169.0 | 219 | 14.1 | 11.9 | 92.0 | 5,801 | 5,459 | 24,440 |
| **1975[5]/** | | | | | | | | |
| Thinned from above: | | | | | | | | |
| 1 | 50.4 | 111 | 19.8 | 9.1 | 88.3 | 1,668 | 1,492 | 4,309 |
| 2 | 99.2 | 239 | 13.5 | 8.7 | 84.0 | 3,105 | 2,742 | 7,273 |
| 3 | 132.9 | 220 | 14.1 | 10.5 | 94.5 | 4,346 | 4,051 | 15,880 |
| 4 | 158.2 | 378 | 10.7 | 8.8 | 86.0 | 4,876 | 4,335 | 13,260 |
| Thinned from below: | | | | | | | | |
| 1 | 55.5 | 58 | 27.4 | 13.3 | 99.1 | 1,925 | 1,825 | 10,005 |
| 2 | 96.5 | 115 | 19.5 | 12.5 | 95.1 | 3,312 | 3,125 | 16,141 |
| 3 | 141.4 | 196 | 14.9 | 11.5 | 96.9 | 4,775 | 4,480 | 19,732 |
| 4 | 183.6 | 219 | 14.1 | 12.4 | 96.4 | 6,274 | 5,914 | 28,440 |

Table 1--Stand characteristics per acre of western larch before and after the 1970 and 1980 thinnings and in 1975[1]--Continued

| Density level[2] | Basal area | Number of trees | Average spacing | Average diameter | Average height[3] | Volume[4] Total | Volume[4] Merchantable, including ingrowth | |
|---|---|---|---|---|---|---|---|---|
| | Square feet | | Feet | Inches | Feet | Cubic feet | Cubic feet | Cubic feet |
| **Before 1980 thinning[5]** | | | | | | | | |
| Thinned from above: | | | | | | | | |
| 1 | 59.3 | 110 | 19.9 | 9.9 | 83.4 | 1,919 | 1,819 | 5,382 |
| 2 | 105.3 | 221 | 14.2 | 9.5 | 81.7 | 3,333 | 3,120 | 8,868 |
| 3 | 152.1 | 220 | 14.1 | 11.3 | 88.5 | 5,022 | 4,712 | 19,103 |
| 4 | 161.9 | 348 | 11.2 | 9.2 | 84.4 | 5,002 | 4,586 | 15,294 |
| Thinned from below: | | | | | | | | |
| 1 | 64.3 | 58 | 27.4 | 14.3 | 101.7 | 2,288 | 2,218 | 11,636 |
| 2 | 107.2 | 115 | 19.5 | 13.2 | 96.8 | 3,729 | 3,591 | 18,869 |
| 3 | 151.5 | 196 | 14.9 | 11.9 | 96.9 | 5,136 | 4,998 | 21,478 |
| 4 | 196.3 | 219 | 14.1 | 12.9 | 97.3 | 6,740 | 6,493 | 32,225 |
| **After 1980 thinning[5]** | | | | | | | | |
| Thinned from above: | | | | | | | | |
| 1 | 53.3 | 98 | 21.1 | 10.0 | 80.4 | 1,726 | 1,636 | 4,921 |
| 2 | 96.2 | 214 | 14.5 | 9.2 | 78.1 | 3,050 | 2,841 | 7,361 |
| 3 | 140.0 | 209 | 14.4 | 11.1 | 85.3 | 4,623 | 4,336 | 17,118 |
| 4 | 160.6 | 347 | 11.2 | 9.2 | 84.0 | 4,958 | 4,543 | 15,082 |
| Thinned from below: | | | | | | | | |
| 1 | 54.9 | 46 | 30.8 | 14.8 | 102.4 | 1,955 | 1,895 | 10,171 |
| 2 | 99.2 | 102 | 21.2 | 13.7 | 98.3 | 3,409 | 3,290 | 17,425 |
| 3 | 139.7 | 175 | 16.0 | 12.3 | 98.3 | 4,782 | 4,659 | 20,402 |
| 4 | 183.6 | 190 | 15.3 | 13.4 | 100.4 | 6,327 | 6,112 | 31,991 |

[1]Based on plots without clearcut strips.
[2]1 is lowest; 4, highest.
[3]Measured with a dendrometer (about 15 trees per plot).
[4]Total cubic-foot volume--entire stem, inside bark, all trees. Merchantable cubic-foot volume--trees 5.0-inch d.b.h. and larger to a 4-inch top d.i.b. Board-foot volume--International 1/4-inch rule, trees 10.0-d.b.h. and larger to a 6-inch top d.i.b.
[5]Basal area, number of trees and volume per acre should be reduced by 29 percent if clearcut strips are included in plot area.

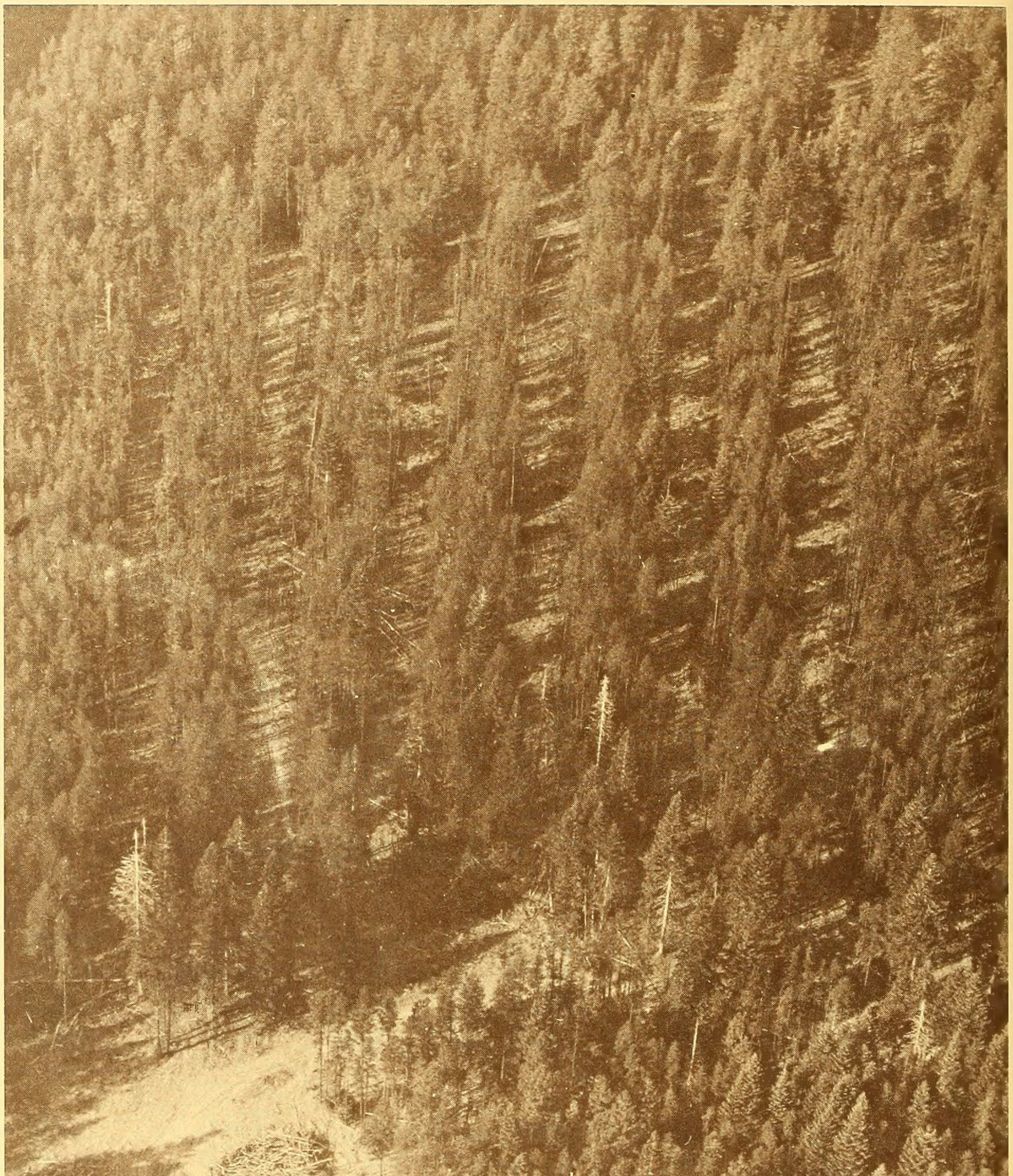

*Figure 1.--Aerial view of part of the thinned area showing alternating thinned and clearcut strips.*

Diameters of all plot trees were measured to the nearest one-tenth inch in the spring of 1970 and the fall of 1974 and 1979. In addition, about 15 trees per plot covering the range of diameters were measured with an optical dendrometer in 1970, 1974, and 1979 to calculate an equation expressing volume of the entire stem inside bark as a function of diameter for each plot. The volume equations developed from the 1970 measurements were used to compute plot volumes (cubic feet and board feet, International 1/4-inch rule) at the beginning and end of the first 5-year period. New equations developed from the 1979 measurement were used to compute plot volumes at the end of the second 5-year period. Height growth was measured by dendrometer only on trees chosen for volume equation measurements.

Because of the mechanized thinning equipment used in this stand, 29 percent of the total area was occupied by clearcut strips, resulting in a reduction in volume growth compared with a thinned area completely occupied by trees. Therefore, growth per acre is presented two ways--based on the 0.286-acre plot completely occupied by trees and on a larger 0.4-acre plot that includes the clearcut strips.

Examination of data on basal area and volume growth for the plot containing 22 percent of the basal area in fir revealed an unusually high growth rate because of the more rapid growth of the fir. Therefore, data from this plot were not used in the growth and statistical analyses.

In 1970 and 1975, an estimate of the natural regeneration present on the low and high density plots (50 and 170 $ft^2$) was obtained by the staff of the Range and Wildlife Habitat Laboratory.[5]

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[5]Personal communication from Gerald S. Strickler, Plant Ecologist, Range and Wildlife Habitat Laboratory, Pacific Northwest Forest and Range Experiment Station, La Grande, Oreg.

## Results

### Mortality and Damage

All mortality occurred in plots thinned from above. Of the 570 trees in these plots, 12 percent died--40 during the first 5-year period and 29 during the second. Death was caused by either windthrow or shock after release. Most of the trees that died were in the intermediate and suppressed crown classes and thus had not developed sufficient windfirmness or large enough crowns to keep pace with the increase respiratory rate after release.

In addition to mortality losses, 53 trees (all but 5 in the plots thinned from above) were leaning at angles estimated to be 10 to 35 degrees from the vertical as a result of wind or ice damage.

In 1976, the larch casebearer (Coleophora laricella Hbn.) moved into the study area and attacked larch in all plots. Dieback of terminals occurred on many trees.

### Diameter Growth

Diameter growth was greatest on the most heavily thinned plots for both thinning methods and both periods (table 2). Average growth during the first period in plots thinned from above declined from 0.1 inch per year at the lowest density level to 0.05 inch at the highest density. In plots thinned from below, growth slowed from 0.16 to 0.09 inch per year as stocking increased. During the second period, in plots thinned from above, the growth rate (0.17 inch per year) at the lowest density was nearly three times the growth at the highest density (0.06 inch per year). These differences in diameter growth rate between growing-stock levels were significant ($P<0.01$) for both periods.

Diameter growth increased significantly ($P<0.01$) from the first to the second period, especially in plots thinned from above where growth at the lowest level was 70 percent greater during the second period. Because of the more rapid diameter growth in plots thinned from above during the second period, a significant ($P<0.01$) interaction existed between growth periods and thinning methods. A significant ($P<0.01$) period-density level interaction also was found because of the relatively greater growth at the low density level during the second period.

A significant ($P<0.05$) linear relationship existed between periodic annual diameter increment and stand density at the beginning of each growth period for both thinning methods (fig. 2). The average growth rate was greater in plots thinned from below during both periods, but because of the increased growth of trees in plots thinned from above during the second period, average diameter growth in these plots during the second period was equal to growth in plots thinned from below during the first period.

Table 2--Periodic annual increment and mortality per acre of western larch by age, density level, and thinning method after initial thinning.

| Density level[1] | Residual basal area | Diameter growth[2] | Basal area growth: Net | Basal area growth: Mortality | Basal area growth: Gross | Total volume growth: Net | Total volume growth: Mortality | Total volume growth: Gross | Merchantable volume growth, including ingrowth: Net | Merchantable volume growth, including ingrowth: Mortality | Merchantable volume growth, including ingrowth: Gross | Ingrowth | Ingrowth | 49 largest trees--diameter growth |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Square feet | Inches | Square feet | | | Cubic feet | | | Board feet | | | Board feet | Percent | Inches |
| **Area without clearcut strips, age 55-60** | | | | | | | | | | | | | | |
| Thinned from above: | | | | | | | | | | | | | | |
| 1 | 51 | 0.10 | -0.04 | 1.12 | 1.08 | 4 | 34 | 38 | 299 | 0 | 299 | 225 | 75.2 | 0.12 |
| 2 | 94 | .08 | 1.08 | .85 | 1.93 | 40 | 25 | 65 | 317 | 0 | 317 | 163 | 51.4 | .12 |
| 3 | 126 | .08 | 1.38 | 1.12 | 2.50 | 51 | 37 | 88 | 378 | 132 | 510 | 202 | 39.6 | .14 |
| 4 | 153 | .05 | 1.04 | .91 | 1.95 | 41 | 24 | 65 | 641 | 0 | 641 | 456 | 71.2 | .09 |
| Thinned from below: | | | | | | | | | | | | | | |
| 1 | 49 | .16 | 1.32 | 0 | 1.32 | 48 | 0 | 48 | 335 | 0 | 335 | 33 | 9.8 | .17 |
| 2 | 88 | .12 | 1.76 | 0 | 1.76 | 68 | 0 | 68 | 528 | 0 | 528 | 109 | 20.6 | .13 |
| 3 | 132 | .08 | 1.92 | 0 | 1.92 | 65 | 0 | 65 | 588 | 0 | 588 | 278 | 47.2 | .10 |
| 4 | 169 | .09 | 2.92 | 0 | 2.92 | 95 | 0 | 95 | 800 | 0 | 800 | 248 | 31.0 | .12 |
| **Area including clearcut strips, age 55-60** | | | | | | | | | | | | | | |
| Thinned from above: | | | | | | | | | | | | | | |
| 1 | 36 | .10 | -0.03 | .81 | .78 | 3 | 24 | 27 | 213 | 0 | 213 | 161 | 75.6 | .12 |
| 2 | 67 | .08 | .78 | .61 | 1.39 | 29 | 18 | 47 | 227 | 0 | 227 | 116 | 49.8 | .12 |
| 3 | 89 | .08 | .98 | .80 | 1.78 | 36 | 26 | 62 | 268 | 94 | 362 | 143 | 39.6 | .14 |
| 4 | 109 | .05 | .74 | .65 | 1.39 | 29 | 18 | 47 | 458 | 0 | 458 | 326 | 71.2 | .09 |
| Thinned from below: | | | | | | | | | | | | | | |
| 1 | 35 | .16 | .94 | 0 | .94 | 34 | 0 | 34 | 239 | 0 | 239 | 24 | 10.0 | .17 |
| 2 | 63 | .12 | 1.25 | 0 | 1.25 | 48 | 0 | 48 | 377 | 0 | 377 | 78 | 20.7 | .13 |
| 3 | 94 | .08 | 1.36 | 0 | 1.36 | 47 | 0 | 47 | 420 | 0 | 420 | 198 | 47.1 | .10 |
| 4 | 121 | .09 | 2.07 | 0 | 2.07 | 68 | 0 | 68 | 571 | 0 | 571 | 177 | 31.0 | .12 |
| **Area without clearcut strips, age 60-65** | | | | | | | | | | | | | | |
| Thinned from above: | | | | | | | | | | | | | | |
| 1 | 50 | .17 | 1.78 | .06 | 1.84 | 50 | 2 | 52 | 215 | 0 | 215 | 83 | 38.6 | .16 |
| 2 | 99 | .10 | 1.22 | 1.10 | 2.32 | 46 | 33 | 79 | 319 | 32 | 351 | 188 | 53.6 | .15 |
| 3 | 133 | .14 | 3.84 | 0 | 3.84 | 135 | 0 | 135 | 645 | 0 | 645 | 267 | 41.4 | .20 |
| 4 | 158 | .06 | .75 | 1.72 | 2.47 | 25 | 50 | 75 | 407 | 84 | 491 | 295 | 60.1 | .11 |
| Thinned from below: | | | | | | | | | | | | | | |
| 1 | 56 | .20 | 1.76 | 0 | 1.76 | 73 | 0 | 73 | 326 | 0 | 326 | 0 | 0 | .21 |
| 2 | 97 | .12 | 2.13 | 0 | 2.13 | 83 | 0 | 83 | 545 | 0 | 545 | 28 | 5.1 | .13 |
| 3 | 141 | .08 | 2.03 | 0 | 2.03 | 72 | 0 | 72 | 350 | 0 | 350 | 96 | 27.4 | .11 |
| 4 | 184 | .09 | 2.55 | 0 | 2.55 | 93 | 0 | 93 | 757 | 0 | 757 | 113 | 14.9 | .13 |
| **Area including clearcut strips, age 60-65** | | | | | | | | | | | | | | |
| Thinned from above: | | | | | | | | | | | | | | |
| 1 | 36 | .17 | 1.27 | .05 | 1.32 | 36 | 1 | 37 | 153 | 0 | 153 | 59 | 38.6 | .16 |
| 2 | 71 | .10 | .86 | .78 | 1.64 | 33 | 23 | 56 | 228 | 23 | 251 | 133 | 53.0 | .15 |
| 3 | 95 | .14 | 2.73 | 0 | 2.73 | 96 | 0 | 96 | 458 | 0 | 458 | 190 | 41.5 | .20 |
| 4 | 113 | .06 | .53 | 1.22 | 1.75 | 18 | 36 | 54 | 289 | 60 | 349 | 209 | 59.9 | .11 |
| Thinned from below: | | | | | | | | | | | | | | |
| 1 | 40 | .20 | 1.25 | 0 | 1.25 | 52 | 0 | 52 | 233 | 0 | 233 | 0 | 0 | .21 |
| 2 | 69 | .12 | 1.52 | 0 | 1.52 | 60 | 0 | 60 | 390 | 0 | 390 | 20 | 5.1 | .13 |
| 3 | 101 | .08 | 1.45 | 0 | 1.45 | 52 | 0 | 52 | 250 | 0 | 250 | 69 | 27.6 | .11 |
| 4 | 131 | .09 | 1.83 | 0 | 1.83 | 66 | 0 | 66 | 541 | 0 | 541 | 81 | 15.0 | .13 |

All columns through Ingrowth refer to all trees.

[1]1 is lowest; 4, highest.
[2]Arithmetic diameter growth of trees living through the 5-year periods.

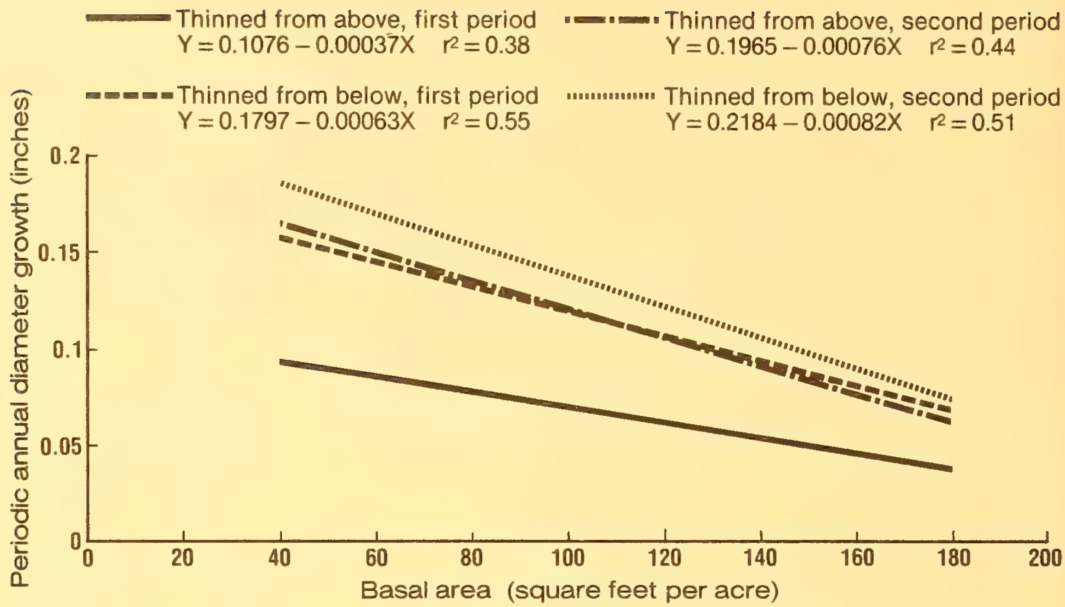


*Figure 2.--Periodic annual diameter growth by density level, thinning method, and growth period.*

Average diameter growth of the 49 largest trees per acre was somewhat greater than growth of all trees (table 2), and differences were more apparent in plots thinned from above and at higher density levels because of more smaller, slower growing trees in these plots.

During the 10 years of this study, the average stand diameter in plots thinned from below increased by 5.9 inches at the lowest density compared with 4.5 inches at the highest density (table 3). Only 20 to 32 percent of this increase, however, was the result of growth; the balance was due to the removal of many small trees in the two thinnings. But even though diameter growth in plots thinned from above was similar to growth in plots thinned from below, the increase in stand diameter after 10 years was much less (0.2 inch to 1.3 inches) because of the large diameter trees removed in the thinnings.

Table 3--Change in average stand diameter of western larch from 1970 to 1979 as a result of growth and two thinnings

| Period and density level[1/] | Change in average diameter | Change attributed to: Thinning | Growth | |
|---|---|---|---|---|
| | Inches | | | Percent |
| **1970-74** | | | | |
| Thinned from above: | | | | |
| 1 | -0.7 | -1.4 | 0.7 | -- |
| 2 | .3 | -.2 | .5 | 167 |
| 3 | .7 | .2 | .5 | 71 |
| 4 | .3 | -.1 | .4 | 133 |
| Thinned from below: | | | | |
| 1 | 4.4 | 3.5 | .9 | 20 |
| 2 | 4.3 | 3.7 | .6 | 14 |
| 3 | 3.2 | 2.8 | .4 | 13 |
| 4 | 3.5 | 3.0 | .5 | 14 |
| **1975-79** | | | | |
| Thinned from above: | | | | |
| 1 | .9 | .1 | .8 | 89 |
| 2 | .5 | -.3 | .8 | 160 |
| 3 | .6 | -.2 | .8 | 133 |
| 4 | .4 | 0 | .4 | 100 |
| Thinned from below: | | | | |
| 1 | 1.5 | .5 | 1.0 | 67 |
| 2 | 1.2 | .5 | .7 | 58 |
| 3 | .8 | .4 | .4 | 50 |
| 4 | 1.0 | .5 | .5 | 50 |
| **1970-79** | | | | |
| Thinned from above: | | | | |
| 1 | .2 | -1.3 | 1.5 | -- |
| 2 | .8 | -.5 | 1.3 | 163 |
| 3 | 1.3 | 0 | 1.3 | 100 |
| 4 | .7 | -.1 | .8 | 114 |
| Thinned from below: | | | | |
| 1 | 5.9 | 4.0 | 1.9 | 32 |
| 2 | 5.5 | 4.2 | 1.3 | 24 |
| 3 | 4.0 | 3.2 | .8 | 20 |
| 4 | 4.5 | 3.5 | 1.0 | 22 |

[1/] 1 is lowest; 4, highest.

## Height Growth

Height growth during the first period was not affected by thinning method or changes in stand density (fig. 3). Only insignificant differences in growth occurred as stocking changed within a thinning method, and there was no significant difference between thinning methods. Increment ranged from 0.64 to 0.88 foot per year in plots thinned from above and from 0.64 to 0.89 foot per year in plots thinned from below.

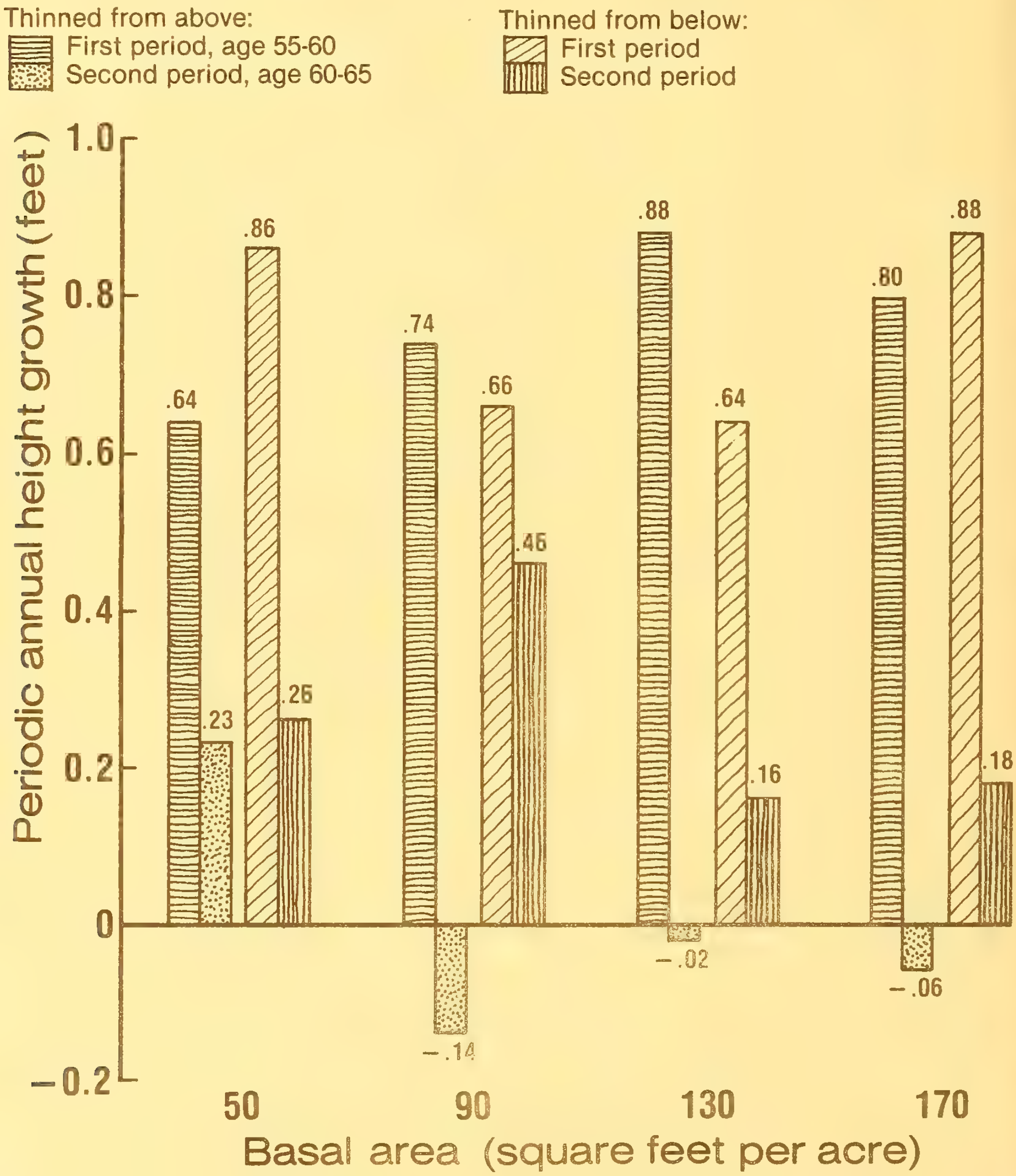


*Figure 3.--Periodic annual height growth by density level, thinning method, and growth period.*

Attacks by the larch casebearer during the second period drastically changed the height growth pattern, resulting in a significant ($P<0.01$) reduction in height growth on all plots and even a negative growth rate on some. Because of top dieback caused by the casebearer, height growth was reduced an average of 91 percent in plots thinned from above and 64 percent in plots thinned from below, a difference approaching significance at the 5-percent level.

## Basal Area Growth

Basal area increment showed an upward trend for both thinning methods during both periods as stocking increased (table 2, figs. 4 and 5). During the first period, the difference in average gross basal area growth between the two methods was not significant (1.87 vs. 1.98 $ft^2$ per acre per year). But because of mortality in plots thinned from above, net basal area growth was significantly greater ($P<0.05$) in plots thinned from below (fig. 4). The regressions of both gross and net basal area growth on stand density were linear ($P<0.05$), and no significant interaction was found between thinning method and stand density.

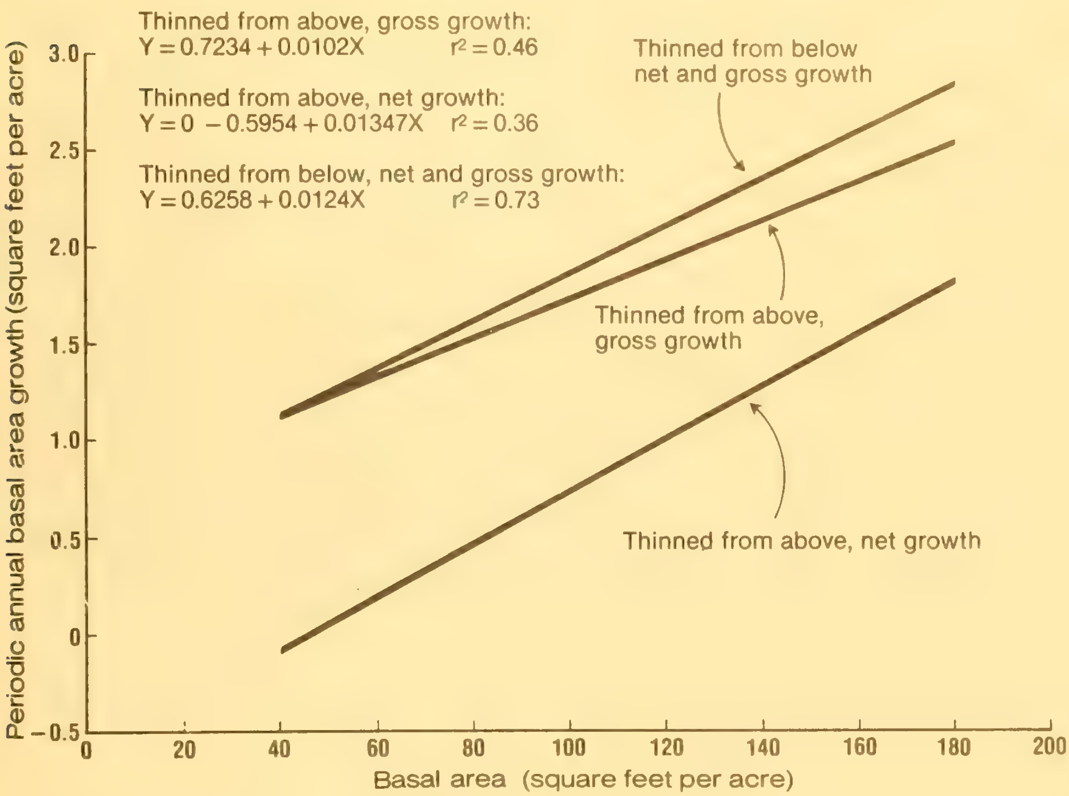


*Figure 4.--Periodic annual basal area growth by density level and thinning method, first period (1970-74). Only one curve for plots thinned from below is shown because net and gross growth are equal because of no mortality.*

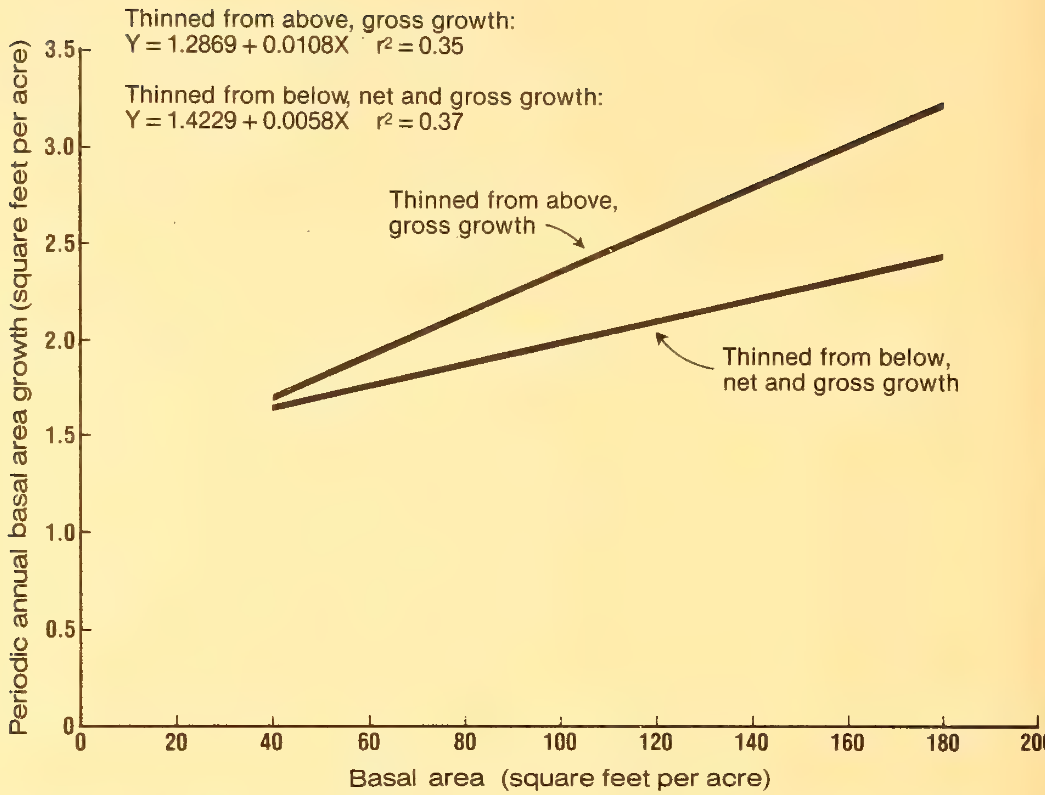


*Figure 5.--Periodic annual basal area growth by density level and thinning method, second period (1975-79). Only one curve for plots thinned from below is shown because net and gross growth are equal because of no mortality. The curve for net growth (thinned from above) is not shown because the net growth-stand density relationship was not significant.*

During the second period, both net and gross growth increased significantly ($P < 0.01$) over growth in the first period--primarily because of the increased growth in plots thinned from above (fig. 5), which resulted in a significant ($P < 0.01$) period-thinning method interaction. All mortality again occurred in plots thinned from above.

## Volume Growth

Total gross cubic volume increment responded to changes in stand density in the same manner as basal area increment--growth increasing as density became greater (table 2). During the first period, cubic volume increment in plots thinned from below was significantly greater than in those thinned from above both in net ($P<0.01$) and gross ($P<0.05$) growth (fig. 6). Mortality caused a loss of 37 to 89 percent of the gross cubic volume growth in plots thinned from above in contrast to no loss in plots thinned from below.

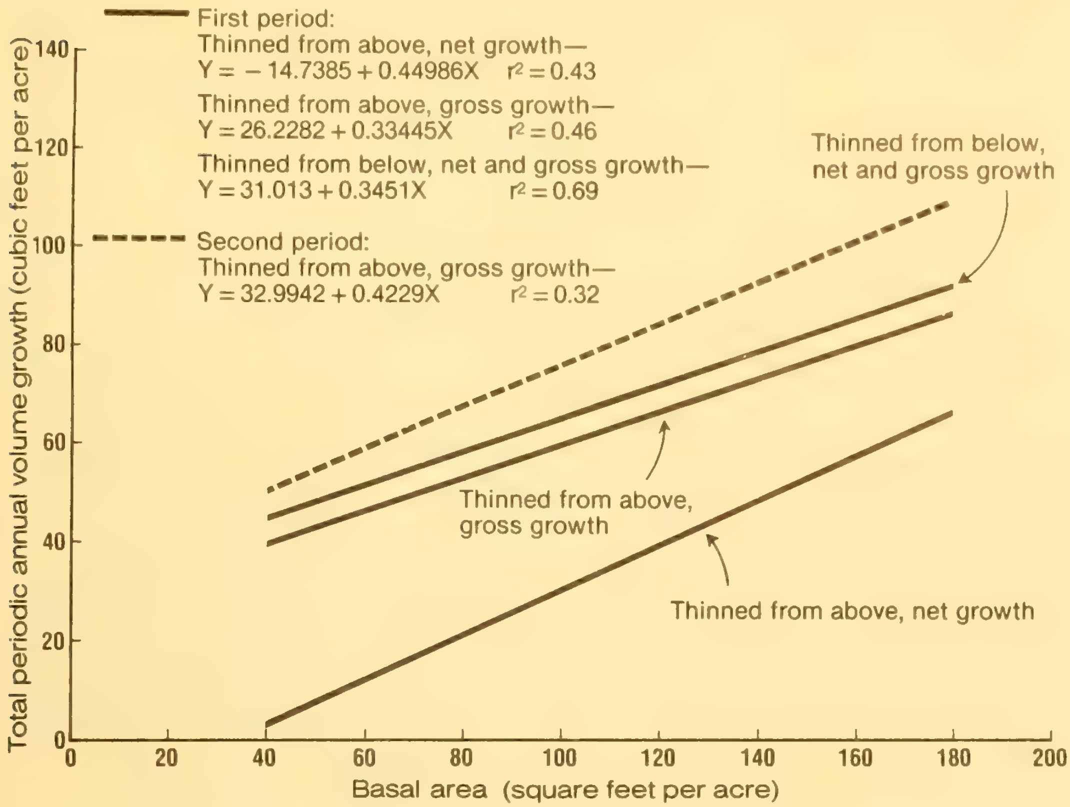


*Figure 6.--Total periodic annual cubic volume growth by density level, thinning method, and growth period. For first period (1970-74) growth, only one curve for plots thinned from below is shown because net and gross growth are equal because of no mortality. For second period (1975-79) growth, only the gross growth (thinned from above) curve is shown because the net (thinned from above and below) and gross (thinned from below) growth-stand density relationships were not significant.*

During the second period, cubic volume growth (net and gross) increased significantly ($P < 0.01$) over that of the first period in plots thinned both from above and below. This increased growth rate was most apparent in plots thinned from above, where gross growth rose from an average of 64 to 85 cubic feet per acre per year and net growth nearly doubled from an average of 34 to 64 cubic feet per acre per year. Again because of considerable mortality (up to 67 percent) in some plots thinned from above, net cubic volume growth was significantly ($P < 0.05$) greater in plots thinned from below. Curves for net and gross growth (thinned from below) are not shown in figure 6 because they did not approach significance.

Although volume increment was generally greater at high stand densities, the volume is distributed over a large number of trees, many of which are smaller and slow growing. Thinning transfers growth to fewer but faster growing trees in addition to utilizing potential mortality. For example, during the first period, in plots thinned from below, 58 trees per acre at the low density produced 51 percent of the cubic volume grown by 219 trees per acre at the high level. During the second period, the low density plots produced 78 percent of the volume grown on the high density plots.

Gross board-foot volume increment increased with greater stand density during both periods, and this linear relationship was significant ($P < 0.01$) (fig. 7). During both growth periods, volume increment was greater in plots thinned from below. This difference was significant ($P < 0.05$) during the first period but not during the second. Board-foot growth decreased significantly ($P < 0.05$) during the second period. Loss of board-foot increment to mortality was light during both periods. Only one tree was lost during the first period and three during the second, all in plots thinned from above. Thus, net growth is similar to gross growth. Ingrowth accounted for a considerable amount of the board-foot growth--from 10 to 75 percent of the volume during the first period and from 0 to 60 percent during the second (table 2).

Culmination of mean annual cubic increment appears to have occurred at all density levels when trees were between 55 and 60 years of age (table 4). Mean annual board-foot increment at various ages appears to be related to stand density. At low densities, culmination occurred near 60 years of age, whereas at higher stocking levels, board-foot increment is still increasing. This increasing growth rate at higher stand densities is probably related to the greater volume of ingrowth at these levels.

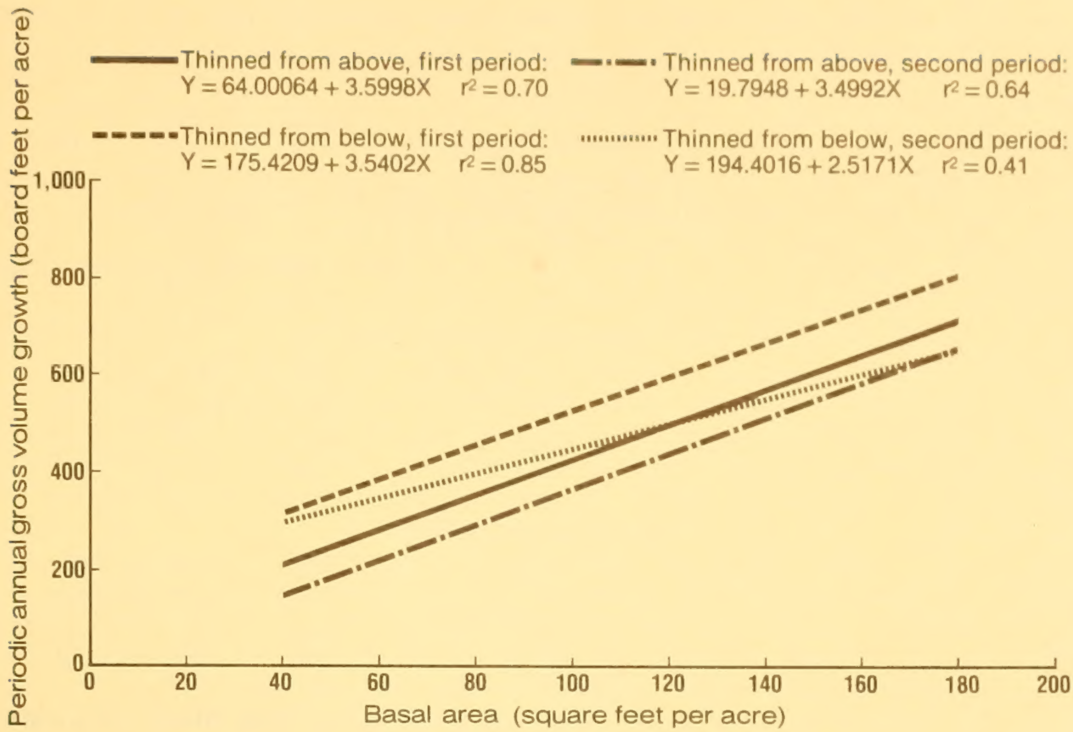


*Figure 7.--Periodic annual gross board-foot (International 1/4-inch rule) volume growth by density level, thinning method, and growth period.*

Thinning with the feller-buncher caused about 29 percent of the total area to be occupied by clearcut strips, with a corresponding 29-percent reduction in volume growth compared with a thinned area completely occupied by trees. The growth and mortality data on an area that includes the clearcut strips are shown in table 2.

## Natural Regeneration

Many seedlings (primarily larch) became established in both plots and clearcut strips after the stand was opened up by the initial thinning. In 1970, there were an average of 1,260 seedlings per acre (all larch) in the low density plots and about 343 grand fir and Douglas-fir seedlings per acre in the high density plots. By 1975, seedlings had increased to an average of 4,356 in the low density plots and 6,075 in the high density plots. The regeneration consisted of 79 percent larch, 8 percent ponderosa pine, and 13 percent grand fir and Douglas-fir in low density plots. At the high density level, 62 percent of the seedlings were larch; 2 percent, pine; and 36 percent, fir. Because of the abundant seedling establishment and good growth during the 10 years after thinning, stand structure in these plots is gradually changing from an even-aged to an uneven-aged condition.

Table 4--Net mean annual increment of western larch per acre

| Basal area | Age 55 | 60 | 65 | Age 55 | 60 | 65 |
|---|---|---|---|---|---|---|
| Square feet per acre | - - - Cubic feet - - - | | | - - - Board feet - - - | | |
| **Area without clearcut strips** | | | | | | |
| Thinned from above: | | | | | | |
| 50 | 130 | 120 | 115 | 488 | 472 | 452 |
| 90 | 110 | 104 | 99 | 337 | 335 | 334 |
| 130 | 125 | 119 | 120 | 491 | 482 | 494 |
| 170 | 114 | 108 | 102 | 328 | 354 | 358 |
| Thinned from below: | | | | | | |
| 50 | 125 | 119 | 115 | 446 | 437 | 429 |
| 90 | 122 | 117 | 115 | 380 | 392 | 363 |
| 130 | 131 | 125 | 121 | 354 | 374 | 372 |
| 170 | 135 | 131 | 128 | 481 | 507 | 527 |
| **Area with clearcut strips** | | | | | | |
| Thinned from above: | | | | | | |
| 50 | 93 | 85 | 82 | 347 | 335 | 321 |
| 90 | 78 | 74 | 70 | 239 | 238 | 237 |
| 130 | 89 | 84 | 85 | 349 | 342 | 351 |
| 170 | 81 | 77 | 72 | 233 | 251 | 254 |
| Thinned from below: | | | | | | |
| 50 | 89 | 84 | 82 | 317 | 310 | 305 |
| 90 | 87 | 83 | 82 | 270 | 278 | 258 |
| 130 | 93 | 89 | 86 | 251 | 266 | 264 |
| 170 | 96 | 93 | 91 | 342 | 360 | 374 |

## Discussion

In spite of heavy infestation of the larch casebearer during the second 5-year period, growth increased. This is most evident in the low density plots thinned from above where diameter growth increased from an average of 0.10 inch per year during the first period to 0.17 inch annually during the second period. Total net cubic volume growth on these plots increased from 4 to 50 cubic feet per acre per year from the first to the second period (table 2). This excellent response is encouraging because of the many larch stands now attacked by the casebearer, although results from this study should not be considered typical of other areas. Also, continued heavy infestations may result in reduced rates of growth. In addition, because larch is intolerant to shade, continued reduction in height growth because of dieback of terminals in young stands can cause larch to lose its competitive advantage to its more shade-tolerant associates and eventually to be eliminated from the stand.

Although growth of trees in plots thinned from above was excellent during the second period, heavy mortality again reduced net volume growth compared with growth in plots thinned from below. Additional mortality of trees already damaged by wind and snow could further reduce stocking levels and growth rates. For these reasons, thinning from below is recommended in previously unmanaged larch stands.

The choice of a residual stocking level after thinning depends on many factors; stand age, frequency of future thinnings, and estimates of the size at which trees will be merchantable in the future should be considered. After stands with an average diameter of 8 to 10 inches are thinned from below, many of the residual trees will be merchantable. In such stands, thinning goals are to utilize mortality, to maintain good volume growth per acre, or to shorten rotations rather than to maintain near-maximum diameter growth. If the management objective is to obtain high volume growth per acre, then a light thinning from below is indicated to utilize anticipated mortality. If, on the other hand, the aim is to shorten the rotation--with a sacrifice of some volume growth--a heavier thinning is suggested.

Although thinning in older stands such as this can result in more rapid diameter and volume growth of residual trees, the greatest gain from thinning seral species (such as larch) is obtained when thinning is begun earlier. Studies in Montana by Schmidt (1966) suggest that the ideal time for precommercial thinning occurs when trees are about 10 years old and from 10 to 15 feet tall. Such early thinning prevents reduction of the crown and concentrates the rapid growth during the sapling and pole stages on crop trees.

Because of the abundant natural regeneration in both clearcut and thinned strips, the land manager has several options: (1) to remove the remaining overstory from the thinned strips and manage the reproduction on the entire area as a single even-aged stand or (2) to retain the overstory at a density level that will result in acceptable growth of both the merchantable sawtimber and the regeneration.

The major conclusions reached in this study after 10 years are:

1. Growth response to stocking level control resulted in less total cubic volume increment per acre but greater diameter and volume growth of individual trees as stand density decreased.
2. Thinning from above in unmanaged larch stands is not desirable because mortality of the smaller residual trees results in reduced volume growth. No mortality occurred in plots thinned from below.
3. Trees responded to increased growing space by more rapid diameter and volume growth despite heavy infestation by the larch casebearer during 4 years of the second 5-year period.

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## Metric Equivalents

1 mile = 1.61 kilometers
1 foot = 0.3048 meter
1 inch = 2.54 centimeters
1 acre = 0.4047 hectare
1 square foot = 0.0929 square meter
1 square foot/acre = 0.2296 square meter/hectare
1 cubic foot/acre = 0.0700 cubic meter/hectare
1 tree/acre = 2.47 trees/hectare

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